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# Almond production in Iran: An analysis of energy use efficiency (2008–2011)

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ABSTRACT

The objective of this study was to analyse input–output energy in almond production in Chahrmahal-Va-Bakhtiari province, Iran. Almond production data were collected from producers using the direct questionnaire method. The results reveal that electricity accounted for a large part of the input energy (50%), followed by chemical fertilizers. The average contributions of human labour, chemicals, farmyard manure, diesel fuel and machinery were 6.89%, 6.77%, 4.70%, 4.66% and 3.59% of the total energy input, respectively. The average values of total energy output, net energy gain and energy efficiency were 140.2 GJ ha$^{-1}$, 77.7 GJ ha$^{-1}$ and 2.24, respectively. In addition, the average values for energy productivity and specific energy were 19 kg GJ$^{-1}$ and 0.06 GJ kg$^{-1}$, respectively. The average values for direct, indirect, renewable and non-renewable forms of energy were 41.6 GJ ha$^{-1}$ (66.63%), 20.9 GJ ha$^{-1}$ (33.36%), 18.3 GJ ha$^{-1}$ (29.21%) and 44.2 GJ ha$^{-1}$ (70.79%), respectively.



**Contents**



## 1. Introduction

Almonds rank first among tree nuts and are very useful food products because of their content of numerous beneficial nutritive and bioactive compounds, such as total lipid (49.22 g/100 g), oleic acid (60.4%), linoleic acid (17.4%), fibre (12.2 g/100 g) and vitamin E (26.22 mg/100 g) [1,2]. Almonds nut can be peeled or unpeeled, raw or roasted and whole or ground, as ingredients in bakery and confectionery products, as well as flavouring agents in beverages and ice-cream [3,4]. Residues from almond trees (pruning and almond shell and hull) can be used as biomass for energy recovery, because of their fairly high energy content (16–18 MJ/kg) [5,6].

Energy inputs are necessary for the global food sector and it is recognized that agricultural crop yields are directly linked to energy [7]. Energy sources used in agriculture consist of two main groups: natural and auxiliary. Natural energy is essential for plant growth and includes solar energy and various forms of chemical energy stored biologically in the soil [8]. To support natural agricultural production processes, auxiliary energy inputs are used by humans so that a given area of land or water produces more than it would do otherwise [9]. This auxiliary energy can be categorized into direct, indirect, renewable and non-renewable energy uses [10]. Agriculture uses energy directly as diesel fuel or electricity to operate machinery and equipment on the farm and indirectly to produce chemical fertilizers, machinery and biocides that are produced off the farm [11]. Non-

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renewable energies include diesel fuel, chemicals, chemical fertilizers, machinery and electricity, while human labour, farmyard manure and water for irrigation are considered renewable energies [11].

Energy consumption in agriculture is increasing in response to a growing population, a limited supply of arable land and a desire for a higher standard of living. However, the intensive use of diesel fuels causes problems that threaten public health and the environment, such as greater greenhouse gas emissions, eutrophication, acidification and water and soil pollution. In addition, if energy prices continue to rise, the global food sector will face increased risks and lower profits [12,13]. Improvements in energy use efficiency are keys for sustainable energy management. To increase energy efficiency, energy input should be reduced without affecting the yield level or increase the production yield [14]. The efficient use of energy in agriculture with low-input energy, compared to the output of agricultural production, would minimize environmental problems such as greenhouse gas emissions and decrease reliance on fossil fuels, as well as improve sustainable agriculture as an economical production system [14]. To determine energy efficiency, energy input–output analyses are usually conducted. These analyses determine how efficiently energy is used [12]. Worldwide energy analysis studies have been conducted by many researchers to determine the energy efficiency in the production of different agricultural crops [15–21]. For this purpose, they have determined the contribution of each energy input, the output–input energy ratio, energy productivity, specific energy, net energy gain and contribution of different energy forms, including direct, indirect, renewable and non-renewable.

To date, there are no published data or information on energy input and output patterns in almond production. Moreover, in previous studies, only the target products' quantity and energy equivalent have been considered as outputs and product residues, which are an important part of agricultural output, have been neglected. Therefore, the main aim of this study was to determine the input–output energy patterns in almond production, in order to reveal the distribution of different energies used during management practices and evaluate the efficiency of input energy consumption. In this study, almond residues were considered as practical and usable energy output resources, therefore their energy contents have been included in the total energy output.

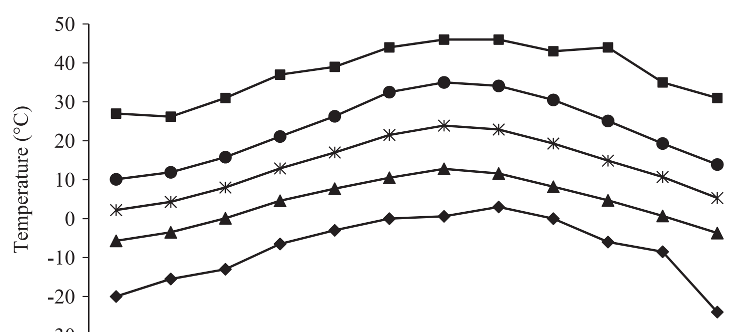
## 2. Materials and methods

This case study was conducted in Chaharmahal-Va-Bakhtiari province, Iran, because of its major contribution to almond production in Iran, with 18.24% of the total production. This region comprises approximately 1% of the total area of Iran and is located on the central Iranian plateau (31°14′, 33°47′N and 49°49′, 51334′E). Climatic indices from 2008 to 2011 were obtained from meteorological stations in the surveyed region and are presented in Fig. 1 and Table 1.

Almond production data were collected from farmers using a face-to-face questionnaire, over three consecutive years (2008–2011), for Sefied, Mamaei, Shahrodi 12 and Rabei cultivars in orchards classified into three age groups: 6–10, 11–15 and 15–20-years-old. A description of the cultivars is provided in Table 2. The

**Table 2**
Description of almond cultivars investigated in this study [22].

| Cultivar | Origin | Shell hardness | Flowering data |
|---|---|---|---|
| Sefied | Iran | Soft | Early |
| Mamaei | Iran | Hard | Medium |
| Rabei | Iran | Hard | Medium |
| Shahrodi 12 | Unknown | Hard | Late |




| | Jan | Feb | Mar | April | May | Jun | July | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Asolute minimum temperature | -20 | -15.5 | -13 | -6.5 | -3 | 0 | 0.6 | 3 | 0 | -6 | -8.5 | -24 |
| Absolute maximum temperature | 27 | 26.2 | 31 | 37 | 39 | 44 | 46 | 46 | 43 | 44 | 35 | 31 |
| Minimum average monthly temperature | -5.7 | -3.5 | 0.1 | 4.6 | 7.7 | 10.5 | 12.8 | 11.6 | 8.2 | 4.7 | 0.7 | -3.7 |
| Maximum average monthly temperature | 10.1 | 11.9 | 15.8 | 21.1 | 26.3 | 32.5 | 35 | 34.1 | 30.5 | 25.1 | 19.3 | 13.9 |
| Average monthly temperature | 2.2 | 4.3 | 8 | 12.9 | 17 | 21.5 | 23.9 | 22.9 | 19.3 | 14.9 | 10.7 | 5.3 |

**Fig. 1.** Principle temperature factors of surveyed region.

**Table 1**
Average amount of some principle climate indices of the surveyed region.

| | Jan | Feb | Mar | April | May | Jun | July | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sunny hours (h) | 213.0 | 220.5 | 243.5 | 235.4 | 313.0 | 354.8 | 353.5 | 347.7 | 316.1 | 275.8 | 218.7 | 186.0 |
| Light ratio | 0.66 | 0.67 | 0.64 | 0.59 | 0.72 | 0.84 | 0.81 | 0.83 | 0.83 | 0.76 | 0.68 | 0.60 |
| Wind speed (m $s^{-1}$) | 6.43 | 5.92 | 4.8 | 4.3 | 3.95 | 4.15 | 4.6 | 5.5 | 5.4 | 6.7 | 7.4 | 7.9 |
| Windless percentage (%) | 12 | 14.8 | 20 | 27.4 | 30 | 25.1 | 20.3 | 16.5 | 18.7 | 13 | 6.6 | 6.9 |
| Frozen days number | 28 | 23 | 15 | 2 | 0 | 0 | 0 | 0 | 0 | 2 | 13 | 24 |
| Precipitation (mm) | 58.2 | 50.2 | 57.4 | 39.8 | 17.1 | 0.6 | 2.3 | 0.18 | 0.3 | 8.1 | 35.3 | 56.9 |
| Relative humidity (%) | 64 | 62 | 58 | 51 | 44 | 38 | 38 | 37 | 40 | 47 | 57 | 61 |

size of the sample in each stratification was calculated using the Cochran formula [23]:

$$n = \frac{N(t \times S)^2}{(N-1)d^2 + (t \times S)^2} \quad (1)$$

where $n$ is the required size, $N$ is the number of holdings in the target population, $t$ is the reliability coefficient (1.96, which represents the 95% reliability), $S^2$ is the variance of the studied qualification in the population and $d$ is the precision (x-X). The impossible error in the sample size was defined to be 5% for 95% confidence.

In this region, the almond production inputs are human labour, machinery, diesel fuel, chemical fertilizers (nitrogen, phosphorus and potassium), farmyard manure, chemicals (insecticides and fungicides), water for irrigation and electricity. The outputs were almond residues and almond nut. The most commonly used operations and practices in almond production in the studied region are listed in Table 3. Because of the geographical conditions of the region, the almond tree-planting pattern was square and the distance between two adjacent trees was usually 5–6 m. Tree pruning was performed mainly in two periods: April–May and November–December, but some farms were occasionally ignored during the April–May pruning period. In the orchards, both chemical fertilizers (nitrogen, phosphorus and potassium) and farmyard manure were used. Spraying was performed three times annually: April–June, October–November and February–March, with an average of 2.87 times per year. Most orchards were on hillsides and water sources were limited; therefore, the drip irrigation method was used and farmers used electrical pumps to transport water to their orchards.

The quantity of the various inputs used and the production outputs were calculated per hectare, based on the information obtained from the questionnaires. Table 4 shows the inputs and outputs of almond production in detail. Horticultural operations were generally conducted by human power in the research region and the results indicate that human power varied from 1230.9 to 3468.9 h/ha. The machinery power and diesel fuel used were in the range 31.4–37.90 h/ha and 44.9–55.3 L/ha. The amount of water used is mainly related to three factors: the plants' water requirement, soil properties and the irrigation method. For individual plants and soil, the drip irrigation system is the most efficient method, as it decreases water consumption significantly in comparison with traditional irrigation methods. As the results show, the values of consumed water varied from 742 $m^3$ $ha^{-1}$ to 1245 $m^3$ $ha^{-1}$ and in all cultivars, older trees consumed much more water than younger ones. The low amount of water used for irrigation in this study was because of the drip irrigation system and the water requirements of almond trees.

The input and output data were multiplied by the corresponding coefficient of energy equivalence (Table 5) to calculate the total input and output energy per hectare, and subsequently energy use efficiency (energy ratio), net energy, energy productivity and specific energy were calculated as follows [23]:

$$\text{Energy efficiency} = \frac{\text{Energy output (GJ ha}^{-1})}{\text{Energy input (GJ ha}^{-1})} \quad (2)$$

$$\text{Net energy} = \text{Energy output (GJ ha}^{-1}) - \text{energy input (GJ ha}^{-1}) \quad (3)$$

$$\text{Energy productivity} = \frac{\text{Almond nut produced (kg ha}^{-1})}{\text{Energy input (GJ ha}^{-1})} \quad (4)$$

$$\text{Specific energy} = \frac{\text{Energy input (GJ ha}^{-1})}{\text{Almond nut produced (kg ha}^{-1})} \quad (5)$$

Energy use efficiency, which is the ratio of the output energy and the total energy inputs, gives an indication of how much energy produced per unit of energy is utilized. Energy productivity provides quantitative data on how much crop is obtained per unit of input energy and specific energy relates to how much energy is consumed per unit of the obtained product. Net energy expresses how much energy is actually gained when energy costs are taken into account, and is defined as the difference between the gross energy output produced and the total energy used for obtaining it.

## 3. Results and discussion

### 3.1. Analysis of input–output energy in almond production

By using energy equivalent per unit of each input and output (Table 5), the quantities of energy for inputs and outputs were obtained. The results are presented in Table 6. The average values of the total energy used and the energy output were 62.5 GJ $ha^{-1}$ and 140.2 GJ $ha^{-1}$, respectively. The contribution of each input is shown in Table 7. As can be seen, more than 50% of the human power was consumed for harvesting and post-harvest operations. For the Sefied

**Table 3**
Practices and operations for almond production.

| Practices/operations | Description |
|---|---|
| Names of almond cultivars | Sefied, Mamaei, Shahrodi 12 and Rabei |
| Tree age (year) | 6–20 |
| Planting pattern | Squarely |
| Planting depth (metre) | 1–1.2 |
| Distance between adjacent trees (metre) | 5–6 |
| Pruning and training period | April–May and November–December |
| Number of Pruning and training (per year) | 1.87 |
| Irrigation method | Dropped |
| Irrigation period | May-August |
| Numbers of irrigation (per year) | 19.78 |
| Chemical fertilization period | March, April–July and October–November |
| Number of chemical fertilization (per year) | 5.13 |
| Farmyard manure period | October |
| Numbers of farmyard manure (per year) | 0.87 |
| Ploughing period | March–April and September–October |
| Numbers of ploughing (per year) | 1.81 |
| Spraying period | April–June, October–November and February–March |
| Numbers of spraying (per year) | 2.87 |
| Harvesting period | August–October |
| Numbers of Harvesting (per year) | 1 |

**Table 4**
Amounts of inputs and outputs (per unit hectare) in the almonds production.

| Cultivar name | Sefied | | | Mamaei | | | Shahrodi 12 | | | Rabei | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tree age (year) | 6–10 | 11–15 | 16–20 | 6–10 | 11–15 | 16–20 | 6–10 | 11–15 | 16–20 | 6–10 | 11–15 | 16–20 |
| ***A. Inputs*** | | | | | | | | | | | | |
| 1. Human labour (h) | | | | | | | | | | | | |
| (a) Ploughing | 250.4 | 269.8 | 291.3 | 233.7 | 251.3 | 277.9 | 261.8 | 274.0 | 290.5 | 245.6 | 269.1 | 292.1 |
| (b) Farmyard manure | 26.3 | 29.2 | 31.5 | 24.3 | 26.8 | 29.5 | 26.4 | 30.1 | 33.2 | 25.4 | 28.8 | 31.2 |
| (c) Irrigation | 155.1 | 157.1 | 156.5 | 154.3 | 150.1 | 155.1 | 154.0 | 152.2 | 153.7 | 155.8 | 155.1 | 152.7 |
| (d) Chemical fertilizer | 114.5 | 118.9 | 121.4 | 113.4 | 116.1 | 120.8 | 115.3 | 119.1 | 125.8 | 114.8 | 118.3 | 121.1 |
| (e) Spraying | 43.3 | 57.3 | 65.5 | 37.9 | 45.5 | 52.1 | 38.7 | 44.1 | 53.4 | 38.0 | 45.0 | 54.4 |
| (f) Pruning and training | 138.3 | 171.0 | 211.0 | 127.1 | 159.2 | 180.5 | 141.4 | 174.0 | 207.3 | 141.5 | 169.8 | 204.8 |
| (g) Harvest and postharvest | 937.8 | 1625.7 | 2591.7 | 540.2 | 943.9 | 785.8 | 1151.8 | 1742.2 | 1986.8 | 1163.0 | 1738.4 | 1993.4 |
| **Total of human labour (h)** | **1665.7** | **2429.0** | **3468.9** | **1230.9** | **1692.9** | **1601.7** | **1889.4** | **2535.7** | **2850.7** | **1884.1** | **2524.5** | **2849.7** |
| 2. Machinery (h) | | | | | | | | | | | | |
| (a) Ploughing | 21.4 | 19.9 | 17.0 | 19.8 | 18.3 | 16.0 | 21.8 | 19.1 | 18.3 | 22.1 | 19.7 | 18.1 |
| (b) Farmyard manure | 0.3 | 0.3 | 0.3 | 0.2 | 0.3 | 0.3 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.3 |
| (c) Spraying | 13.2 | 15.9 | 17.3 | 11.9 | 12.5 | 14.1 | 13.7 | 16.1 | 18.4 | 14.0 | 15.0 | 17.4 |
| (e) Transport | 1.3 | 1.1 | 2.0 | 1.4 | 1.2 | 1.0 | 1.4 | 1.2 | 1.0 | 1.4 | 1.1 | 1.3 |
| **Total of machinery (h)** | **36.2** | **37.2** | **36.6** | **33.3** | **32.3** | **31.4** | **37.1** | **36.6** | **37.9** | **37.7** | **36.0** | **37.1** |
| 3. Diesel fuel (L) | | | | | | | | | | | | |
| (a) Ploughing | 35.3 | 32.8 | 28.1 | 32.7 | ‘30.2 | 26.5 | 36.0 | 31.6 | 30.2 | 36.4 | 32.6 | 29.9 |
| (b) Farmyard manure | 0.6 | 0.5 | 0.5 | 0.5 | 0.6 | 0.5 | 0.4 | 0.5 | 0.5 | 0.4 | 0.4 | 0.6 |
| (c) Spraying | 15.3 | 18.4 | 21.8 | 13.1 | 14.0 | 16.1 | 15.3 | 18.4 | 22.7 | 16.3 | 18.4 | 19.8 |
| (d) Transport | 1.9 | 1.8 | 1.7 | 1.9 | 1.8 | 1.8 | 1.8 | 1.9 | 1.9 | 1.9 | 1.8 | 1.9 |
| **Total of diesel fuel (L)** | **53.1** | **53.5** | **52.1** | **48.2** | **46.6** | **44.9** | **53.5** | **52.4** | **55.3** | **55.0** | **53.2** | **52.2** |
| 4. Chemical fertilizers (kg) | | | | | | | | | | | | |
| (a) Nitrogen (N) | 115.7 | 126.3 | 154.6 | 117.6 | 125.0 | 148.3 | 126.0 | 141.3 | 178.9 | 129.8 | 146.1 | 179.4 |
| (b) Phosphorus ($P_2O_5$) | 111.0 | 118.2 | 132.2 | 112.7 | 117.0 | 124.1 | 123.4 | 138.9 | 174.5 | 126.5 | 139.8 | 173.3 |
| (c) Potassium ($K_2O$) | 37.9 | 42.5 | 51.5 | 34.0 | 39.4 | 53.8 | 40.6 | 49.6 | 59.9 | 41.6 | 49.2 | 61.0 |
| **Total of chemical fertilizers (kg)** | **264.6** | **287.0** | **338.3** | **264.3** | **281.4** | **326.2** | **290.0** | **329.8** | **413.3** | **297.9** | **335.1** | **413.7** |
| **5. Farmyard manure (kg)** | **9324.3** | **9854.4** | **10,434.3** | **9000.8** | **9451.3** | **10,075.4** | **9373.3** | **9903.6** | **10,474.0** | **9328.2** | **9832.9** | **10,412.3** |
| 6. Chemicals (kg) | | | | | | | | | | | | |
| (a) Insecticides | 30.2 | 34.7 | 39.1 | 27.1 | 32.7 | 36.1 | 31.7 | 35.0 | 39.1 | 29.7 | 33.9 | 38.3 |
| (b) Fungicides | 3.6 | 3.7 | 4.0 | 3.4 | 3.6 | 3.8 | 3.6 | 3.7 | 3.9 | 3.6 | 3.8 | 4.0 |
| **Total of chemicals (kg)** | **33.8** | **38.4** | **43.1** | **30.5** | **36.3** | **39.9** | **35.3** | **38.7** | **43.0** | **33.3** | **37.7** | **42.3** |
| **7. Water ($m^{3)}$** | **829.4** | **1172.0** | **1520.1** | **827.5** | **1170.1** | **1516.8** | **827.9** | **1171.4** | **1519.7** | **827.4** | **1171.5** | **1519.6** |
| **8. Electricity (kWh)** | **2665.8** | **2632.5** | **2606.4** | **2793.9** | **2876.3** | **2792.5** | **2974.9** | **2832.0** | **2855.0** | **2805.5** | **2837.5** | **2858.6** |
| ***B. Outputs*** | | | | | | | | | | | | |
| **1. Almond nut (kg)** | **637.2** | **1110.2** | **1747.4** | **517.0** | **991.0** | **734.4** | **1149.4** | **1674.4** | **1936.2** | **1070.5** | **1606.4** | **1840.1** |
| 2. Almond residues (kg) | | | | | | | | | | | | |
| (a) Shell | 542.8 | 945.8 | 1488.6 | 919.0 | 1761.3 | 1305.6 | 2134.6 | 3109.6 | 3595.8 | 2173.5 | 3261.6 | 3735.9 |
| (b) Hull | 507.4 | 884.1 | 1391.5 | 646.2 | 1238.4 | 918.1 | 1461.4 | 2128.9 | 2461.7 | 1476.0 | 2214.9 | 2537.1 |
| (c) Tree pruning | 2306.3 | 3522.8 | 4105.5 | 1839.3 | 3019.0 | 3591.6 | 2384.4 | 3536.0 | 4155.0 | 2342.6 | 3489.9 | 4093.5 |
| **Total of almond residues (kg)** | **3356.5** | **5352.7** | **6985.6** | **3404.5** | **6018.7** | **5815.3** | **5980.4** | **8774.5** | **10,212.5** | **5992.1** | **8966.4** | **10,366.5** |

**Table 5**
Energy equivalent of inputs and output in almond production.

| Particulars | Unit | Energy equivalent (MJ $unit^{-1}$) | References |
|---|---|---|---|
| *A. Inputs* | | | |
| 1. Human labour | h | 1.96 | [24,25,26] |
| 2. Machinery | h | 62.7 | [25,27] |
| 3. Diesel fuel | L | 56.31 | [24,27,28] |
| 4. Chemical fertilizers | kg | | |
| (a) Nitrogen (N) | | 66.14 | [12,24,29,30] |
| (b) Phosphorus ($P_2O_5$) | | 12.44 | [12,24,29,30] |
| (c) Potassium ($K_2O$) | | 11.15 | [12,24,30,31] |
| 5. Farmyard manure | kg | 0.3 | [25,27,32] |
| 6. Chemicals | kg | | [25,30,32] |
| (a) Insecticides | | 101.2 | |
| (c) Fungicides | | 216 | |
| 7. Water | $m^3$ | 1.02 | [30,33] |
| 8. Electricity | kWh | 11.93 | [26,32] |
| *B. Output* | kg | | |
| 1. Almond nut | | 24.08 | [2] |
| 2. Almond residues | | | |
| (a) Shell | | 18 | [5,6] |
| (b) Hull | | 16 | [5,6] |
| (c) Tree pruning | | 18.13 | [5,6] |

cultivar, this value was higher than that for the other cultivars, because hulling was carried out only by hand, whereas the others were hulled by machine. The results show that the energy consumed by farmyard manure and chemicals was in the range 2.7–3.2 GJ $ha^{-1}$ (5% of the total energy input) and 3.8–4.8 GJ $ha^{-1}$ (7% of the total energy input), respectively. Ozkan et al. reported values of farmyard manure energy inputs of 0.76, 0.99 and 0.64 GJ $ha^{-1}$ for orange, lemon and mandarin production, respectively [25]. These are very small values compared with the results obtained in the present study. Farmyard manure, which is used in farms and orchards to improve the physical properties of the soil, has no noticeable nutrient value and its consumption amount is mainly related to the physical properties of the soil. The results (Table 7) reveal that machinery consumed approximately 3.19–3.97% of the total input energy during the production period. In all the orchards, machinery was mainly used for ploughing and spraying operations. Chemical fertilizers (mainly nitrogen) consumed approximately 16–22% of the energy. For all the cultivars, chemical fertilizers consumption increased as tree age increased. The two main reasons for the high consumption of chemical fertilizers were the ignorance of farmers and the low cost. Unfortunately, most farmers do not use chemical fertilizers

**Table 6**
Amounts of energy equivalent of inputs and outputs in the almonds production.

| | Energy equivalent (GJ $ha^{-1}$) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cultivar name | Sefied | | | Mamaei | | | Shahrodi 12 | | | Rabei | | |
| Tree age (year) | 6–10 | 11–15 | 16–20 | 6–10 | 11–15 | 16–20 | 6–10 | 11–15 | 16–20 | 6–10 | 11–15 | 16–20 |
| ***A. Inputs*** | | | | | | | | | | | | |
| 1. Human labour | | | | | | | | | | | | |
| (a) Ploughing | 0.491 | 0.529 | 0.571 | 0.458 | 0.492 | 0.545 | 0.513 | 0.537 | 0.569 | 0.481 | 0.527 | 0.572 |
| (b) Farmyard manure | 0.051 | 0.057 | 0.062 | 0.048 | 0.052 | 0.058 | 0.052 | 0.059 | 0.065 | 0.050 | 0.056 | 0.061 |
| (c) Irrigation | 0.304 | 0.308 | 0.307 | 0.303 | 0.294 | 0.304 | 0.302 | 0.298 | 0.301 | 0.305 | 0.304 | 0.299 |
| (d) Chemical fertilizer | 0.224 | 0.233 | 0.238 | 0.222 | 0.227 | 0.237 | 0.226 | 0.233 | 0.246 | 0.225 | 0.232 | 0.237 |
| (e) Spraying | 0.085 | 0.112 | 0.128 | 0.074 | 0.089 | 0.102 | 0.076 | 0.086 | 0.105 | 0.074 | 0.088 | 0.107 |
| (f) Pruning and training | 0.271 | 0.335 | 0.414 | 0.249 | 0.312 | 0.354 | 0.277 | 0.341 | 0.406 | 0.227 | 0.333 | 0.401 |
| (g) Harvest and postharvest | 1.838 | 3.186 | 5.080 | 1.058 | 1.850 | 1.540 | 2.258 | 3.415 | 3.894 | 2.280 | 3.407 | 3.907 |
| **Total of human labour** | **3.264** | **4.760** | **6.798** | **2.412** | **3.317** | **3.140** | **3.704** | **4.969** | **5.586** | **3.692** | **4.947** | **5.584** |
| 2. Machinery | | | | | | | | | | | | |
| (a) Ploughing | 1.340 | 1.247 | 1.068 | 1.244 | 1.147 | 1.005 | 1.367 | 1.200 | 1.147 | 1.384 | 1.237 | 1.137 |
| (b) Farmyard manure | 0.021 | 0.017 | 0.016 | 0.014 | 0.020 | 0.016 | 0.013 | 0.015 | 0.014 | 0.013 | 0.012 | 0.019 |
| (c) Spraying | 0.827 | 0.994 | 0.1084 | 0.743 | 0.782 | 0.882 | 0.856 | 1.006 | 1.152 | 0.876 | 0.943 | 1.092 |
| (e) Transport | 0.082 | 0.070 | 0.125 | 0.088 | 0.073 | 0.063 | 0.090 | 0.076 | 0.063 | 0.086 | 0.071 | 0.081 |
| **Total of machinery** | **2.270** | **2.328** | **2.293** | **2.089** | **2.022** | **1.966** | **2.326** | **2.297** | **2.376** | **2.359** | **2.263** | **2.329** |
| 3. Diesel fuel | | | | | | | | | | | | |
| (a) Ploughing | 1.985 | 1.848 | 1.583 | 1.843 | 1.699 | 1.489 | 2.025 | 1.778 | 1.699 | 2.051 | 1.833 | 1.684 |
| (b) Farmyard manure | 0.032 | 0.029 | 0.028 | 0.026 | 0.033 | 0.028 | 0.024 | 0.026 | 0.026 | 0.024 | 0.023 | 0.032 |
| (c) Spraying | 0.859 | 1.037 | 1.227 | 0.738 | 0.787 | 0.908 | 0.861 | 1.038 | 1.278 | 0.917 | 1.038 | 1.116 |
| (d) Transport | 0.105 | 0.101 | 0.098 | 0.108 | 0.101 | 0.103 | 0.104 | 0.108 | 0.105 | 0.105 | 0.102 | 0.107 |
| **Total of diesel fuel** | **2.981** | **3.015** | **2.936** | **2.715** | **2.620** | **2.528** | **3.014** | **2.950** | **3.108** | **3.097** | **2.996** | **2.939** |
| 4. Chemical fertilizers | | | | | | | | | | | | |
| (a) Nitrogen | 7.650 | 8.354 | 1.0225 | 7.776 | 8.265 | 9.809 | 8.336 | 9.345 | 11.829 | 8.584 | 9.662 | 11.864 |
| (b) Phosphorus | 1.381 | 1.470 | 1.644 | 1.402 | 1.455 | 1.544 | 1.535 | 1.728 | 2.171 | 1.574 | 1.739 | 2.155 |
| (c) Potassium | 0.423 | 0.475 | 0.574 | 0.379 | 0.439 | 0.600 | 0.453 | 0.553 | 0.668 | 0.464 | 0.548 | 0.680 |
| **Total of chemical fertilizers** | **9.454** | **10.299** | **12.443** | **9.557** | **10.159** | **11.953** | **10.324** | **11.626** | **14.668** | **10.621** | **11.949** | **14.699** |
| **5. Farmyard manure** | **2.797** | **2.956** | **3.130** | **2.700** | **2.835** | **3.023** | **2.812** | **2.971** | **3.142** | **2.798** | **2.950** | **3.124** |
| 6. Chemicals | | | | | | | | | | | | |
| (a) Insecticides | 3.051 | 3.513 | 3.954 | 2.748 | 3.310 | 3.650 | 3.210 | 3.546 | 3.958 | 3.007 | 3.431 | 3.872 |
| (b) Fungicides | 0.771 | 0.806 | 0.860 | 0.732 | 0.773 | 0.825 | 0.779 | 0.799 | 0.851 | 0.775 | 0.812 | 0.858 |
| **Total of chemicals** | **3.822** | **4.319** | **4.814** | **3.480** | **4.083** | **4.475** | **3.989** | **4.345** | **4.809** | **3.782** | **4.243** | **4.730** |
| **7. Water** | **0.744** | **0.991** | **1.245** | **0.742** | **0.989** | **1.241** | **0.742** | **0.991** | **1.244** | **0.742** | **0.991** | **1.244** |
| **8. Electricity** | **31.803** | **31.405** | **31.094** | **33.332** | **34.315** | **33.315** | **35.491** | **33.786** | **34.060** | **33.469** | **33.851** | **34.103** |
| **Total inputs** | **57.135** | **60.073** | **64.753** | **57.027** | **60.340** | **61.641** | **62.402** | **63.935** | **68.993** | **60.560** | **64.190** | **68.752** |
| ***B. Outputs*** | | | | | | | | | | | | |
| **1. Almond nut** | **11.599** | **26.735** | **42.078** | **12.448** | **23.856** | **17.685** | **27.678** | **40.320** | **46.623** | **25.778** | **38.683** | **44.309** |
| **2. Almond residues** | | | | | | | | | | | | |
| (a) Shell | 9.770 | 17.024 | 26.794 | 16.543 | 31.703 | 23.501 | 38.423 | 55.973 | 64.725 | 39.122 | 58.708 | 67.247 |
| (b) Hull | 8.118 | 14.145 | 22.264 | 10.339 | 19.814 | 14.690 | 23.382 | 34.062 | 39.388 | 23.616 | 35.439 | 40.593 |
| (c) Tree pruning | 41.812 | 63.869 | 74.433 | 33.346 | 54.735 | 65.116 | 43.229 | 64.107 | 75.330 | 42.470 | 63.272 | 74.215 |
| **Total of almond residues** | **59.700** | **95.038** | **123.491** | **60.228** | **106.252** | **103.307** | **105.034** | **15.4142** | **17.9443** | **105.208** | **157.419** | **182.055** |
| **Total outputs** | **71.299** | **121.773** | **165.569** | **72.676** | **130.108** | **120.992** | **132.712** | **194.462** | **226.066** | **130.986** | **196.102** | **226.364** |

according to the plants' requirements, soil chemical properties and other important factors, as they believe that the excessive use of chemical fertilizers will increase their yield. Often, the amount of chemical fertilizers applied to an orchard was related to the financial status of the farmer. Ozkan el al. reported that the energy equivalent of chemical fertilizers in citrus is approximately 44.42%, 49.68% and 45.79% of the total energy input for orange, lemon and mandarin production, respectively [25]. Their results also showed that nitrogen accounted for most of the energy input in citrus production. Because of the drip irrigation system, electric water pumps were used to lift water from the Zayanderood river. Electricity in the region is supplied by hydropower (30%) and fossil fuel (70%) sources. The electricity used by water pumps was in the range 2600–2900 kWh $ha^{-1}$, with an energy equivalent of approximately 31–36 GJ $ha^{-1}$ (more than 50% of the total energy input).

As the results show (Table 7), the average proportions of almond nut and almond residue of the total output energy were approximately 80% and 20%, respectively. It was found that tree pruning and almond hull had the maximum and minimum proportions of the output energy, respectively.

### 3.2. Energy indices

Table 8 shows energy input and output, energy use efficiency, energy productivity, specific energy and net energy. The maximum and minimum amounts of energy efficiency were 3.08 and 1.14, belonging to the Rabei cultivar (6–10-year-old orchards) and the Sefied cultivar (16–20-year-old orchards), respectively. Energy efficiency for the Sefied, Shahrodi 12 and Rabei cultivars exhibited an increasing trend according to tree age, but for the Mamaei cultivar the maximum value obtained was in the age group 11–15. Many researchers have reported the energy efficiency of different agricultural products, such as apple (1.16) [18], rice (1.53) [8],

**Table 7**
Percentage of energy equivalent of inputs and outputs in the almonds production.

| | Percentage of total (%) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cultivar name | Sefied | | | Mamaei | | | Shahrodi 12 | | | Rabei | | |
| Tree age (year) | 6–10 | 11–15 | 16–20 | 6–10 | 11–15 | 16–20 | 6–10 | 11–15 | 16–20 | 6–10 | 11–15 | 16–20 |
| ***A. Inputs*** | | | | | | | | | | | | |
| 1. Human labour | | | | | | | | | | | | |
| (a) Ploughing | 0.86 | 0.88 | 0.88 | 0.80 | 0.82 | 0.88 | 0.82 | 0.84 | 0.82 | 0.79 | 0.82 | 0.83 |
| (b) Farmyard manure | 0.09 | 0.09 | 0.09 | 0.08 | 0.09 | 0.09 | 0.08 | 0.09 | 0.09 | 0.08 | 0.09 | 0.09 |
| (c) Irrigation | 0.53 | 0.51 | 0.47 | 0.53 | 0.49 | 0.49 | 0.48 | 0.47 | 0.44 | 0.50 | 0.47 | 0.43 |
| (d) Chemical fertilizer | 0.39 | 0.39 | 0.37 | 0.39 | 0.38 | 0.38 | 0.36 | 0.36 | 0.36 | 0.37 | 0.36 | 0.34 |
| (e) Spraying | 0.15 | 0.19 | 0.20 | 0.13 | 0.15 | 0.16 | 0.12 | 0.13 | 0.15 | 0.12 | 0.14 | 0.15 |
| (f) Pruning and training | 0.47 | 0.56 | 0.64 | 0.44 | 0.52 | 0.57 | 0.44 | 0.53 | 0.59 | 0.37 | 0.52 | 0.58 |
| (g) Harvest and postharvest | 3.22 | 5.30 | 7.84 | 1.85 | 3.07 | 2.50 | 3.62 | 5.34 | 5.64 | 3.76 | 5.31 | 5.68 |
| **Total of human labour** | **5.71** | **7.92** | **10.50** | **4.23** | **5.50** | **5.09** | **5.93** | **7.77** | **8.10** | **6.10** | **7.71** | **8.12** |
| 2. Machinery | | | | | | | | | | | | |
| (a) ploughing | 2.34 | 2.07 | 1.65 | 2.18 | 1.90 | 1.63 | 2.19 | 1.88 | 1.66 | 2.28 | 1.93 | 1.65 |
| (b) Farmyard manure | 0.04 | 0.03 | 0.02 | 0.02 | 0.03 | 0.03 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.03 |
| (c) Spraying | 1.45 | 1.65 | 1.67 | 1.30 | 1.29 | 1.43 | 1.37 | 1.57 | 1.67 | 1.44 | 1.47 | 1.59 |
| (e) Transport | 0.14 | 0.11 | 0.19 | 0.15 | 0.12 | 0.10 | 0.14 | 0.12 | 0.09 | 0.14 | 0.11 | 0.12 |
| **Total of machinery** | **3.97** | **3.87** | **3.54** | **3.66** | **3.35** | **3.19** | **3.73** | **3.59** | **3.44** | **3.89** | **3.52** | **3.38** |
| 3. Diesel fuel | | | | | | | | | | | | |
| (a) Ploughing | 3.47 | 3.07 | 2.44 | 3.23 | 2.81 | 2.42 | 3.25 | 2.78 | 2.46 | 3.39 | 2.85 | 2.45 |
| (b) Farmyard manure | 0.05 | 0.05 | 0.04 | 0.04 | 0.05 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.03 | 0.04 |
| (c) Spraying | 1.50 | 1.73 | 1.89 | 1.29 | 1.30 | 1.47 | 1.38 | 1.62 | 1.85 | 1.51 | 1.62 | 1.62 |
| (d) Transport | 0.18 | 0.17 | 0.15 | 0.19 | 0.17 | 0.17 | 0.16 | 0.17 | 0.15 | 0.17 | 0.16 | 0.15 |
| **Total of diesel fuel** | **5.22** | **5.02** | **4.53** | **4.76** | **4.34** | **4.10** | **4.83** | **4.61** | **4.50** | **5.11** | **4.67** | **4.27** |
| 4. Chemical fertilizers | | | | | | | | | | | | |
| (a) Nitrogen (N) | 13.39 | 13.90 | 15.79 | 13.63 | 13.70 | 15.91 | 13.36 | 14.61 | 17.14 | 14.17 | 15.05 | 17.25 |
| (b) Phosphorus ($P_2O_5$) | 2.42 | 2.45 | 2.54 | 2.46 | 2.41 | 2.50 | 2.46 | 2.70 | 3.14 | 2.60 | 2.71 | 3.13 |
| (c) Potassium ($K_2O$) | 0.74 | 0.79 | 0.89 | 0.66 | 0.73 | 0.97 | 0.73 | 0.86 | 0.97 | 0.76 | 0.85 | 0.99 |
| **Total of chemical fertilizers** | **16.55** | **17.14** | **19.21** | **16.76** | **16.83** | **19.39** | **16.54** | **18.18** | **21.25** | **17.54** | **18.61** | **21.38** |
| **5. Farmyard manure** | **4.89** | **4.92** | **4.83** | **4.73** | **4.70** | **4.90** | **4.50** | **4.65** | **4.55** | **4.62** | **4.59** | **4.54** |
| 6. Chemicals | | | | | | | | | | | | |
| (a) Insecticides | 5.34 | 5.85 | 6.10 | 4.82 | 5.48 | 5.92 | 5.14 | 5.54 | 5.74 | 4.96 | 5.34 | 5.63 |
| (b) Fungicides | 1.35 | 1.34 | 1.33 | 1.28 | 1.28 | 1.34 | 1.25 | 1.25 | 1.23 | 1.28 | 1.26 | 1.25 |
| **Total of chemicals** | **6.69** | **7.19** | **7.43** | **6.10** | **6.77** | **7.26** | **6.39** | **6.79** | **6.97** | **6.24** | **6.61** | **6.88** |
| **7. Water** | **1.30** | **1.65** | **1.92** | **1.30** | **1.64** | **2.01** | **1.19** | **1.55** | **1.80** | **1.22** | **1.54** | **1.81** |
| **8. Electricity** | **55.66** | **52.28** | **48.02** | **58.45** | **56.87** | **54.04** | **56.87** | **52.84** | **49.36** | **55.26** | **52.73** | **49.60** |
| ***B. Outputs*** | | | | | | | | | | | | |
| **1. Almond nut** | **16.27** | **21.95** | **25.41** | **17.13** | **18.34** | **14.62** | **20.85** | **20.73** | **20.62** | **19.68** | **19.73** | **19.57** |
| 2. Almond residues | | | | | | | | | | | | |
| (a) Shell | 13.70 | 13.98 | 16.18 | 22.76 | 24.37 | 19.42 | 28.95 | 28.78 | 28.63 | 29.87 | 29.94 | 29.71 |
| (b) Hull | 11.39 | 11.62 | 13.45 | 14.23 | 15.23 | 12.14 | 17.62 | 17.51 | 17.42 | 18.03 | 18.07 | 17.93 |
| (c) Tree pruning | 58.64 | 52.45 | 44.96 | 45.88 | 42.07 | 53.82 | 32.57 | 32.97 | 33.32 | 32.42 | 32.26 | 32.79 |
| **Total of almond residues** | **83.73** | **78.05** | **74.59** | **82.87** | **81.66** | **85.38** | **79.15** | **79.27** | **79.38** | **80.32** | **80.27** | **80.43** |

potato (average 1.05) [34], canola (3.02) [32], corn silage (average 2.27) [23] and corn (2.59) [35].

The energy productivity values obtained show that per unit energy (GJ), 8.4–28.1 kg of almond nuts were produced in the region. These values are low in comparison to values reported in the literature for agricultural products such as potato (270–320 kg $GJ^{-1}$) [34], rice (80–100 kg $GJ^{-1}$) [8], barberry (320–430 kg $GJ^{-1}$) [36], canola (120 kg $GJ^{-1}$) [32], stake-tomato (100 kg $GJ^{-1}$) [31], cotton (60 kg $GJ^{-1}$) [24], orange (656 kg $GJ^{-1}$), lemon (555 kg $GJ^{-1}$), mandarin (614 kg $GJ^{-1}$) [25], sugar beet (1530 kg $GJ^{-1}$) [37] and apple (490 kg $GJ^{-1}$) [18]. The main reason for this difference relates to natural differences between agricultural plants and products. The net energy for almonds increased from 14.164 GJ $ha^{-1}$ to 157.612 GJ $ha^{-1}$. The distribution of total energy inputs as different forms is presented in Table 9. The total energy input consumed can be classified as ;direct energy (64–69%), indirect energy (31–36%), renewable energy (27.80–31.66%) and non-renewable energy (68.34–72.20%) in almond orchards. The electricity consumed was the main reason for the difference between direct and indirect energy inputs in almond production in the area. Several researchers have reported higher direct energy than indirect energy inputs for various agricultural products, such as lemon (55.85% and 44.82%, respectively) and mandarin (52.83% and 46.79%) [25], apple (51.38% and 48.62%) [18], canola (57.35% and 42.75%) [32], stake-tomato (55% and 43.1%) [31] and cherries (52% and 48%) [38].

The heavy reliance of almond production on non-renewable energy resources raises concerns about their supply availability and certain price increases in the coming years. In rural areas, renewable energy systems can provide several benefits for landowners, businesses and rural communities. These systems can play a key role in improving energy access and alleviate energy poverty in low-gross domestic product (low-GDP) countries. In fact, increasing the use of renewable energy sources can help the food production sector achieve sustained development [18].

**Table 8**
Energy input–output ratio in the almonds production.

| Items | Unit | Cultivar | Tree age (year) | | |
|---|---|---|---|---|---|
| | | | 6–10 | 11–15 | 16–20 |
| Energy input | $GJ\ ha^{-1}$ | Sefied | 57.135 | 60.073 | 64.753 |
| | | Mamaei | 57.027 | 60.340 | 61.641 |
| | | Shahrodi 12 | 62.402 | 63.935 | 68.993 |
| | | Rabei | 60.560 | 64.190 | 68.752 |
| Energy output | $GJ\ ha^{-1}$ | Sefied | 71.299 | 121.773 | 165.569 |
| | | Mamaei | 72.676 | 130.108 | 120.992 |
| | | Shahrodi 12 | 132.712 | 194.462 | 226.066 |
| | | Rabei | 130.986 | 196.102 | 226.364 |
| Energy efficiency | – | Sefied | 1.25 | 2.03 | 2.56 |
| | | Mamaei | 1.27 | 2.16 | 1.96 |
| | | Shahrodi 12 | 2.13 | 3.04 | 3.28 |
| | | Rabei | 2.16 | 3.06 | 3.29 |
| Energy productivity | $kg\ GJ^{-1}$ | Sefied | 11 | 18 | 27 |
| | | Mamaei | 9 | 16 | 12 |
| | | Shahrodi 12 | 18 | 26 | 28 |
| | | Rabei | 18 | 25 | 27 |
| Specific energy | $GJ\ kg^{-1}$ | Sefied | 0.0897 | 0.0541 | 0.0371 |
| | | Mamaei | 0.110 | 0.0610 | 0.0839 |
| | | Shahrodi 12 | 0.0543 | 0.0382 | 0.0356 |
| | | Rabei | 0.0566 | 0.0400 | 0.0374 |
| Net energy | $GJ\ ha^{-1}$ | Sefied | 14.164 | 61.700 | 100.816 |
| | | Mamaei | 15.649 | 69.768 | 59.351 |
| | | Shahrodi 12 | 70.310 | 130.527 | 157.073 |
| | | Rabei | 70.426 | 131.912 | 157.612 |

**Table 9**
Amount of different forms of total input energy for the almonds production and their percentages.

| Form of energy | Cultivar | Tree age (year) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 6–10 | | 11–15 | | 16–20 | |
| | | Quantity ($GJ\ ha^{-1}$) | Percentage (%) | Quantity ($GJ\ ha^{-1}$) | Percentage (%) | Quantity ($GJ\ ha^{-1}$) | Percentage (%) |
| Direct energy | Sefied | 38.792 | 67.89 | 40.171 | 66.87 | 42.073 | 64.97 |
| | Mamaei | 39.201 | 68.74 | 41.241 | 68.35 | 40.224 | 65.24 |
| | Shahrodi 12 | 42.951 | 68.83 | 42.696 | 66.78 | 43.998 | 63.77 |
| | Rabei | 41.000 | 67.70 | 42.785 | 66.65 | 43.870 | 63.81 |
| Indirect energy | Sefied | 18.343 | 32.10 | 19.902 | 33.13 | 22.680 | 35.02 |
| | Mamaei | 17.826 | 31.26 | 19.099 | 31.65 | 21.417 | 34.74 |
| | Shahrodi 12 | 19.451 | 31.17 | 21.239 | 33.22 | 24.995 | 36.23 |
| | Rabei | 19.560 | 32.30 | 21.405 | 33.34 | 24.882 | 36.19 |
| Renewable energy | Sefied | 16.346 | 28.61 | 18.129 | 30.18 | 20.501 | 31.66 |
| | Mamaei | 15.854 | 27.80 | 17.436 | 28.90 | 17.399 | 28.23 |
| | Shahrodi 12 | 17.905 | 28.69 | 18.947 | 29.63 | 20.190 | 29.26 |
| | Rabei | 17.273 | 28.52 | 19.043 | 29.67 | 20.183 | 29.36 |
| Non-renewable energy | Sefied | 40.789 | 71.39 | 41.944 | 69.82 | 44.252 | 68.34 |
| | Mamaei | 41.173 | 72.20 | 42.904 | 71.10 | 44.242 | 71.77 |
| | Shahrodi 12 | 44.497 | 71.31 | 44.988 | 70.37 | 48.803 | 70.74 |
| | Rabei | 43.287 | 71.48 | 45.147 | 70.33 | 48.569 | 70.64 |

Direct energy: human labour, diesel fuel, electricity and water for irrigation.
Indirect energy: seeds, chemical fertilizers, farmyard manure, chemicals and machinery.
Renewable energy: human labour, farmyard manure, water for irrigation and hydroelectricity.
Non-renewable energy: diesel fuel, chemicals, chemical fertilizers, machinery and electricity generated by fossil fuels.

## 4. Conclusions

In this study, energy use patterns in almond production in the Chaharmahal-Va-Bakhtiari province, Iran, of the four most popular cultivars was investigated. For each cultivar, orchards were divided into three strata based on tree age (6–10, 11–15 and 16–20-years-old). Considering the results obtained, the following conclusions can be drawn:

1- The total energy used in almond production ranged from 57.027 $GJ\ ha^{-1}$ to 68.993 $GJ\ ha^{-1}$.
2- Electricity consumed the most energy in all the almond orchards (50% of the total energy input), followed by chemical fertilizers (approximately 16–22% of the total energy input).
3- Water for irrigation was the least demanding energy input (approximately 1.2–2%) and the main reason for this was the drip irrigation system.
4- The average values of total energy output, energy efficiency and net energy gain were 140.2 $GJ\ ha^{-1}$, 2.24 and 77.7 $GJ\ ha^{-1}$, respectively.
5- The average values of energy productivity and specific energy were 19 $kg\ GJ^{-1}$ and 0.061 $GJ\ kg^{-1}$, respectively.

6- The average values of direct, indirect, renewable and non-renewable forms of energy were 41.584 GJ $ha^{-1}$ (66.63%), 20.901 GJ $ha^{-1}$ (33.36%), 18.267 GJ $ha^{-1}$ (29.21%) and 44.216 GJ $ha^{-1}$ (70.79%), respectively. Electricity used by water pumps was the main reason for the high quantity of direct and non-renewable forms of energy input.

We recommend that the consumption of chemical fertilizers is scientifically managed so that they can be effectively used, resulting in a reduction of soil and environment population, a possible decrease in energy input and a financial saving. In addition, it is possible to decrease human labour by using machinery.

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